TENSION DETECTION APPARATUS OF
ENDLESS LOOP POWER TRANSFERRING MEMBER AND
TORQUE DETECTION APPARATUS USING THE SAME

BACKGROUND OF THE INVENTION

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The present invention relates to a tension detection
apparatus of an endless loop power transferring member used
for transmitting torque from a drive source to a driven device
10 and a torque detection apparatus using the same.

For example, a vehicle has auxiliary devices, or driven
devices, that are driven by a drive source, or an engine, by
way of an endless loop power transferring member. Such
15 devices include a compressor in a refrigeration circuit of a
vehicle air conditioner (for example, Japanese Laid-Open
Patent Publication No. 2001-132634). In the technique
disclosed in Japanese Laid-Open Patent Publication No. 2001-
132634, a magnetic piece is attached to a pulley, which
20 rotates integrally with a rotary shaft. Alternatively, a
piezoelectric element is embedded in a shock absorbing rubber
member located between a rotary shaft and a pulley. The
magnetic piece or the piezoelectric element is deformed by
applied torque. Such deformation is converted into an
25 electric signal. The signal is sent to a primary coil of a
transformer provided on the pulley, and then sent to a
secondary coil located on a housing of a compressor, through a
wire attached to the pulley. However, attaching the wire to
the pulley, or a rotor, is troublesome.
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In Japanese Laid-Open Patent Publication No. 2001-132634,
a magnetic piece is attached to a pulley, and a magnetic
sensor is provided at a part of the housing that faces the
magnetic piece. There have been proposed techniques in which
35 a magnetic sensor detects changes in flux created by a

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magnetic piece to detect torque.

However, when a member for detecting torque, such as a magnetic piece or a piezoelectric element, is attached to a rotor, the rotor becomes unbalanced. Therefore, it is not desirable to provide a rotor with a member for detecting torque.

The pulley of Japanese Laid-Open Patent Publication No. 2001-132634 is rotatably supported by a boss of the housing through which the rotary shaft extends. Thus, unbalanced load acting on the pulley due to torque acts on the boss, or a supporting member, through a bearing. Therefore, for example, it may be configured that deformation of the boss is detected, and torque is detected by referring to the correlation between the unbalanced load and the torque.

However, since the boss is part of the housing and rigid, the boss is not easily deformed. This results in low detection accuracy. Forming the boss to be easily deformed degrades the strength of the boss. That is, if the configuration in which deformation of the boss is detected is used, the requirements for the strength of the boss and the detection accuracy cannot be simultaneously satisfied. Such a configuration is therefore not desirable.

SUMMARY OF THE INVENTION

Accordingly, it is an objective of the present invention to provide an improved tension detection apparatus of an endless loop power transferring member and a torque detection apparatus using the same.

To achieve the above-mentioned objective, the present invention provides a tension detection apparatus. The

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apparatus detects tension acting on an endless loop power
transferring member that transfers torque from a drive source
to at least one driven device. The apparatus includes a
supporting member and a bearing attached to the supporting
5   member. A rotor is rotatably supported by the supporting
member with the bearing in between. The power transferring
member is engaged with the rotor. A deformation member is
located between the supporting member and the bearing. The
amount of deformation of the deformation member varies in
10   accordance with the tension of the power transferring member.
A deformation detection device detects the deformation amount
of the deformation member at at least two positions that are
spaced from each other in a circumferential direction of the
bearing. Based on the deformation amount detected by the
15   deformation detection device, a computer computes unbalanced
load that is applied to the supporting member by the tension
of the power transferring member through the rotor, the
bearing, and the deformation member. Based on the computed
unbalanced load, the computer computes the tension of the
20   power transferring member.

        According to another aspect of the invention, a torque
detection apparatus for detecting torque transmitted to a
driven device by a drive source through an endless loop power
25   transferring member is provided. The driven device has a
housing and a rotor. The rotor is rotatably supported by the
housing with a bearing. A section of the power transferring
member is engaged with the rotor. The apparatus includes a
deformation member located between the housing and the
30   bearing. The amount of deformation of the deformation member
varies in accordance with the tension of the power
transferring member. A deformation detection device detects
the deformation amount of the deformation member at at least
two positions that are spaced from each other in a
35   circumferential direction of the bearing. Based on the

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deformation amount detected by the deformation detection
device, a computer computes unbalanced load that is applied to
the housing by the tension of the power transferring member
through the rotor, the bearing, and the deformation member.
5   Based on the computed unbalanced load, the computer computes
tension of an advancing section and tension of a trailing
section of the power transferring member in the moving
direction of the power transferring member with respect to the
rotor. Based on the difference between the computed tensions,
10 the computer computes the torque.

Other aspects and advantages of the invention will become
apparent from the following description, taken in conjunction
with the accompanying drawings, illustrating by way of example
15 the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with objects and advantages
20 thereof, may best be understood by reference to the following
description of the presently preferred embodiments together
with the accompanying drawings in which:

Fig. 1 is a cross-sectional view illustrating a power
25 transmission mechanism according to one embodiment of the
present invention;
Fig. 1A is an enlarged view illustrating the tension
detection apparatus of Fig. 1;
Fig. 2 is a perspective view illustrating a tolerance
30 ring;
Fig. 3 is a diagrammatic partially cross-sectional view
taken along line III-III of Fig. 1; and
Fig. 4 is a diagrammatic view showing the relationship
between a crankshaft and auxiliary devices.
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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

One embodiment of the present invention will now be described.

As shown in Fig. 1, a power transmission mechanism is provided between an engine E, which is a drive source of a vehicle, and a refrigerant compressor C of a refrigeration cycle of a vehicle air conditioner. The compressor C has a housing 11. A compression mechanism P is accommodated in the housing 11. A rotary shaft 12 for driving the compression mechanism P is rotatably supported by the housing 11. A supporting member, which is a boss 13, is formed on the housing 11. The rotary shaft 12 extends through the boss 13. A rotor, which is a compressor pulley 14, is fixed to an end of the rotary shaft 12 by fastening a bolt 16. The compressor pulley 14 and the rotary shaft 12 rotate integrally.

A crankshaft pulley 17 (see Fig. 4) is fixed to a crankshaft of the engine E. The crankshaft pulley 17 rotates integrally with the crankshaft. An endless loop power transferring member, which is an endless belt 18, is engaged with the outer circumference of the compressor pulley 14 and the crankshaft pulley 17. Therefore, power of the engine E, or torque, is transmitted to the rotary shaft 12 by way of the belt 18 and the compressor pulley 14, which causes the compression mechanism P to compress refrigerant gas. The compression mechanism P may be of a piston type, a scroll type, or a vane type. Further, the compression mechanism P may be of a fixed displacement type or a variable displacement type.

As shown in Fig. 1 and Fig. 1A, a ring groove 13a is formed in the outer circumference of the boss 13. A tolerance ring 19, which functions as a deformation member and an

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annular member, is located in the ring groove 13a.

As shown in Fig. 2, the tolerance ring 19 includes a
cylindrical portion 19a and curved portions 19b protruding
5   radially outward from the cylindrical portion 19a. The
tolerance ring 19 is made of metal, for example, steel.

As shown in Fig. 1, a bearing 20 is located radially
outward of the tolerance ring 19. The compressor pulley 14 is
10   rotatably supported by the boss 13 with the bearing 20 and the
tolerance ring 19. The boss 13 does not contact the bearing
20. The bearing 20 is a roller bearing and includes an inner
race 21, an outer race 22, and rolling bodies, which are balls
23 in this embodiment. The balls 23 are located between the
15   races 21, 22. The tolerance ring 19 is installed to be
located between the boss 13 of the housing 11 and the inner
race 21 of the bearing 20, such that the curved portions 19b
are deformed radially inward when the engine E is not running.

20   In Fig. 3, for purposes of illustration, the rotary shaft
12, which is located radially inward of the boss 13, is
omitted. Also, the number of the curved portions 19b is less
than the actual number in Fig. 3.

25   As shown in Fig. 3, deformation sensors, which are two
strain gauges 26, 27, are each attached to different one of
the curved portions 19b of the tolerance ring 19. The strain
gauges 26, 27 function as a strain detection device. The
strain gauges 26, 27 are each attached to the radially inner
30   surface of the corresponding curved portion 19b such that the
strain gauges 26, 27 are spaced apart by 90°. The output data
of the strain gauges 26, 27 are sent to a controller 28, which
is a computer, through a wire 28a indicated by a two-dot chain
line.

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As shown in Fig. 3, the controller 28 computes unbalanced load F acting on the boss 13 based on the output data of the strain gauges 26, 27. The unbalanced load F acts on the boss 13 according to the tension of the belt 18 through the
5 compressor pulley 14, the bearing 20, and the tolerance ring 19. Based on the computed unbalanced load F, the controller 28 computes the tension T1, T2 of the belt 18. The tolerance ring 19, the strain gauges 26, 27, and the controller 28 form a tension detection apparatus of the endless loop power
10 transferring member, which is the belt 18. Based on the computed tension T1, T2 of the belt 18, the controller 28 computes compressor torque M1, which is transmitted from the engine E to the compressor C through the belt 18. Therefore, the tension detection apparatus also functions as a torque
15 detection apparatus that computes the torque transmitted to an auxiliary device, or a driven device (a compressor C in this embodiment).

The operation of the tension detection apparatus will now
20 be described. When the engine E is running, the belt 18 receives a tension T1 in a trailing section and a tension T2 in an advancing section in the moving direction with respect to the compressor pulley 14. The unbalanced load F, which is the resultant of the tensions T1, T2, acts on the boss 13 by
25 way of the belt 18, the compressor pulley 14, the bearing 20, and the tolerance ring 19. Accordingly, the curved portions 19b of the tolerance ring 19 are deformed by the unbalanced load F from an initial deformed state in which the engine E is not running, and the deformation is measured by the strain
30 gauges 26, 27.

Based on the output data of the strain gauges 26, 27, the controller 28 computes the vector of the unbalanced load F, that is, the magnitude and the direction of the unbalanced
35 load F. Specifically, based on the output data of the strain

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gauges 26, 27, the controller 28 computes loads Fa, Fb, which loads Fa, Fb act on portions of the tolerance ring 19, to which the strain gauges 26, 27 are attached, from the belt 18 through the compressor pulley 14 and the bearing 20. The controller 28 then computes the resultant of the loads Fa, Fb to compute the unbalanced load F. Since the directions of the tensions T1, T2 are determined based on the orientations of sections of the belt 18 at the advancing and trailing sections of the compressor pulley 14, the controller 28 decomposes the vector of the unbalanced load F to obtain components in the advancing section and the trailing section, thereby obtaining the tensions T1, T2.

When the radius of the compressor pulley 14 is represented by R1 (see Fig. 4), the compressor torque M1 satisfies the following equation.

$$M1 = (T1 - T2) R1 \quad \text{Equation (1)}$$

Therefore, if the radius R1 is memorized in the controller 28 in advance, the controller 28 is capable of computing the compressor torque M1 from the equation (1) by detecting the tensions T1, T2.

As shown in Fig. 4, in this embodiment, the belt 18 is engaged with the crankshaft pulley 17, the compressor pulley 14, and a power steering pulley 29. The power steering pulley 29 rotates integrally with the rotary shaft of a hydraulic pump in a power steering unit. The compressor pulley 14 is located in a trailing section of the belt 18 in the moving direction with respect to the crankshaft pulley 17. The power steering pulley 29 is located in a trailing section of the belt 18 in the moving direction with respect to the compressor pulley 14, or in an advancing section with respect to the crankshaft pulley 17. The compressor C is a first driven

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device that is located adjacent to and in a trailing side with respect to a section of the belt 18 that is engaged with the crankshaft pulley 17, or the engine E. The power steering unit is a second driven device that is located adjacent to and

5   in an advancing section with respect to the section of the belt 18. A tension pulley 30 is located at a section of the belt 18 between the crankshaft pulley 17 and the power steering pulley 29. The tension pulley 30 is urged by a spring 30a. The tension pulley 30 and the spring 30a function

10   as a tension applying mechanism that applies tension to the belt 18 so that the belt 18 is not loosened. The tension applying mechanism is located adjacent to the engine E and in the advancing section.

15   When the engine E is running, a section of the belt 18 at the trailing side of the power steering pulley 29 receives the tension T2, and a section of the belt 18 at the advancing side of the power steering pulley 29 receives a tension T3. The torque for driving the tension pulley 30 is significantly

20   smaller than torque M1 for driving the compressor pulley 14 or the torque for driving the power steering pulley 29 and therefore need not be considered. Thus, a section of the belt 18 at the advancing side of the crankshaft pulley 17 receives the tension T3.

25   A section of the belt 18 at the trailing side of the crankshaft pulley 17 receives the tension T1. Load torque applied to the engine E by the crankshaft pulley 17 and the power steering pulley 29, that is, a load torque M0 of all the

30   auxiliary devices, which are the compressor C and the power steering unit, is expressed by the following equation when the diameter of the crankshaft pulley 17 is represented by R0.

$$M0 = (T1 - T3)\ R0 \quad \text{Equation (2)}$$

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The tension T3 is a tension that is applied to the belt
18 by the tension pulley 30, which is urged by the spring 30a.
The tension T3 is obtained by detecting the force of the
spring 30a with an applied force detection device, which is a
5   load cell 31. The output data of the load cell 31 is sent to
the controller 28 through a wire 31a. Therefore, when the
tension T1 is obtained with the tolerance ring 19 and the
strain gauges 26, 27 in the compressor C, the load torque M0
applied to the engine E by all the auxiliary devices is
10   obtained referring to the relationship between the tension T1,
T3 and the load torque M0 (using the equation (2)). The
tension detection apparatus of the endless loop power
transferring member and the load cell 31 form a torque
detection apparatus for detecting the load torque M0 applied
15   to the engine E by all the auxiliary devices.

The above-described embodiment provides the following
advantages.

20   (1) The bearing 20 is provided at the boss 13 (supporting
member) of the housing 11 with the tolerance ring 19 in
between. The compressor pulley 14 (rotor), with which the
belt 18 is engaged, is rotatably supported with the bearing
20. The strain gauges 26, 27 are attached to the tolerance
25   ring 19. The positions of the strain gauges 26, 27 are
displaced from each other in the circumferential direction.
The controller 28 computes the unbalanced load F based on the
output data of the strain gauges 26, 27. The controller 28
then obtains the tensions T1, T2 of the belt 18 at the
30   advancing and trailing sides based on the unbalanced load F.

Therefore, since the compressor torque M1 can be computed
based on the tensions T1, T2, no member for detecting torque
is required for the pulley 14, that is, no member for
35   detecting torque is attached to the pulley 14, and the
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compressor pulley 14 is prevented from being unbalanced.

The torque M1 is computed based on detected deformation
of the tolerance ring 19, not based on detected deformation of
the boss 13. Therefore, the supporting member need not be
configured to be easily deformed. Accordingly, the strength
of the boss 13 is maintained while improving the detection
accuracy.

(2) The deformation member is the tolerance ring 19.
Therefore, compared to a case where the deformation member
comprises discontinuous members that support the bearing 20 at
at least three positions, the illustrated embodiment permits
the deformation member to be easily provided by installing the
tolerance ring 19 between the boss 13 and the bearing 20.
Also, the configuration reduces the number of the components.

(3) The bearing 20 is a roller bearing. The tolerance
ring 19 is located between the boss 13 and the inner race 21
of the bearing 20. Therefore, it is easy to prevent
rotational force of the pulley 14 from being transmitted to
the tolerance ring 19. Thus, the unbalanced load F is easily
and accurately obtained. The durability of the tolerance ring
19 is easily improved.

(4) The compressor C with the tolerance ring 19 is
located at a section of the belt 18 at the trailing side of
the engine E. The tension pulley 30 is located at a section
of the belt 18 at the advancing side of the engine E.
Therefore, the controller 28 is capable of obtaining the load
torque M0 applied to the engine E by all the auxiliary devices
using the equation (2) simply by detecting the tension T1 with
the tolerance ring 19 and the tension T3 with the tension
pulley 30 and the load cell 31.

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The invention may be embodied in the following forms.

In the illustrated embodiment, the tension pulley 30 and
the spring 30a apply the tension T3 to the belt 18. However,
5 the tension pulley 30 and the spring 30a may be omitted.

An initial tension T0 is applied to the belt 18, so that
friction exists between the belt 18 and the pulleys 14, 17,
29, and that the belt 18 is engaged with the pulleys 14, 17,
10 29 to transmit torque between the belt 18 and the pulleys 14,
17, 29. When the engine E is not running, the tensions T1,
T2, T3, T0 are all equal (T1 = T2 = T3 = T0). The controller
28 is capable of obtaining the initial tension T0 by detecting
the tension T1 or the tension T2 when the engine E is not
15 running (either of the tensions T1, T2 is equal to the initial
tension T0).

When the engine E is started from a stopped state, the
tension T1 of a section of the belt 18 at the trailing side of
20 the crankshaft pulley 17 becomes greater than the initial
tension T0, and the tension T3 of a section of the belt 18 at
the advancing side of the crankshaft pulley 17 becomes less
than the initial tension T0. Thus, the tensions T1, T3 and
the initial tension T0 can be approximately expressed by the
25 following equations.

When inequalities (T0 <) $T1 < 2\sqrt{(T0)}$ and $0 < T3$ (<T0)
are satisfied,

30      $(\sqrt{(T1)} + \sqrt{(T3)})/2 = \sqrt{(T0)}$ Equation (3)

When an inequality $2\sqrt{(T0)} \leq T1$ is satisfied,

T3 = 0   Equation (4)
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Therefore, the controller 28 is capable of obtaining the tension T3 using one of the equations (3) and (4) based on the tension T1 detected at the compressor pulley 14, and the initial tension T0. The controller 28 then obtains the load

5 torque M0 using the equation (2) based on the obtained tensions T1, T3.

If T3 is canceled in the equations (2) and (3), the load torque M0 is expressed by the following equation.

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When inequalities $(T0 <)$ $T1 < 2\sqrt{}(T0)$ and $0 < T3$ $(<T0)$ are satisfied,

$$M0 = 4(\sqrt{}(T0 \cdot T1) - T0)R0 \quad \text{Equation (5)}$$

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Referring to the equations (2) and (4), the load torque M0 is expressed by the following equation.

When an inequality $2\sqrt{}(T0) \leq T1$ is satisfied,

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$$M0 = T1 \cdot R0 \quad \text{Equation (6)}$$

Therefore, the controller 28 is capable of obtaining the load torque M0 using one of the equations (5) and (6).

25

In the above illustrated embodiment, the unbalanced load F is obtained after obtaining the load Fa and the load Fb at two points based on the output data of the strain gauges 26, 27. However, the unbalanced load F may be obtained by the

30 following procedure. That is, the correlation between the output data of the strain gauges 26, 27 at the points and the unbalanced load F is obtained in advance. Without obtaining the loads Fa, Fb at two points, the unbalanced load F is obtained directly from the output data of the strain gauges

35 26, 27 based on the correlation.

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In the illustrated embodiment, the compressor pulley 14
is located at a section of the belt 18 at the trailing side of
the crankshaft pulley 17, and the power steering pulley 29 is
5   located at a section of the belt 18 at the advancing side of
the crankshaft pulley 17. This configuration may be changed
such that the compressor pulley 14 is located at the advancing
side of the crankshaft pulley 17, and the power steering
pulley is located at the trailing side of the crankshaft
10   pulley 17.

To obtain the load torque M0 applied to the engine E by
all the auxiliary devices when the tension pulley 30 and the
load cell 31 are provided in the above-mentioned case, the
15   tolerance ring 19 is located between a supporting member that,
with a bearing, rotatably supports the power steering pulley
29 and the bearing. The controller 28 obtains at the power
steering pulley 29 the tension of a section of the belt 18 at
the trailing side of the crankshaft pulley 17 from the output
20   data of the strain gauges 26, 27. The tension at the
advancing side of the crankshaft pulley 17 is obtained from
the output data of the load cell 31. Based on the obtained
tensions, the controller 28 computes the load torque M0. When
the tension pulley 30 and the load cell 31 are not provided,
25   the controller 28 detects the initial tension T0 in a state
where the engine E is not running, and computes the load
torque M0 using one of the equations (5) and (6).

The auxiliary devices receiving torque from the belt 18
30   are not limited to the compressor C and the power steering
unit. However, for example, a hydraulic pump for a brake
assisting apparatus, an air pump for an air suspension
apparatus, or a water pump may be added to the auxiliary
devices so that three or more auxiliary devices receive torque
35   from the belt 18.

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To obtain the load torque M0 when the tension pulley 30 and the load cell 31 are provided in the above-mentioned case, the tolerance ring 19 is provided in an auxiliary device

5　corresponding to a section of the belt 18 that is adjacent to and in a trailing section with respect to a section corresponding to the crankshaft pulley 17. Specifically, the tolerance ring 19 is located between a supporting member that, with a bearing, rotatably supports a pulley, or a rotor, of

10　the auxiliary device and the bearing. The controller 28 obtains the tension of a section of the belt 18 at the trailing side of the crankshaft pulley 17 from the output data of the strain gauges 26, 27. Also, the controller 28 obtains the tension of the advancing side of the belt 18 based on the

15　output data of the load cell 31. Based on the obtained tensions, the controller 28 computes the load torque M0. When the tension pulley 30 and the load cell 31 are not provided, the controller 28 computes the load torque M0 using one of the equations (5) and (6).

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If each auxiliary device has the tolerance ring 19 and the strain gauges 26, 27, torque for driving each auxiliary device will be computed by the controller 28. Only one auxiliary device may receive torque from the belt 18.

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When an idle pulley 33 (shown by broken line in Fig. 4) is provided between the crankshaft pulley 17 and the compressor pulley 14, that is, at the trailing section of the belt 18 with respect to the crankshaft pulley 17, the

30　tolerance ring 19 may be located between a supporting member that, with a bearing, rotatably supports the idle pulley 33 and the bearing.

To obtain the load torque M0 applied to the engine E by

35　all the auxiliary devices when the tension pulley 30 and the

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load cell 31 are provided in the above-mentioned case, the
tension of the belt 18 at the idle pulley 33 is detected,
thereby obtaining the tension of a section of the belt 18 at
the trailing side of the crankshaft pulley 17, which trailing
5   side tension is equal to the tension at the idle pulley 33.
The tension of a section of the belt 18 at the advancing side
of the crankshaft pulley 17 is obtained based on the output
data of the load cell 31. Accordingly, the load torque M0 is
computed. When the tension pulley 30 and the load cell 31 are
10   not provided, the controller 28 computes the load torque M0
using one of the equations (5) and (6).

The strain gauges 26, 27 need not be spaced by 90°
interval as long as the strain gauges 26, 27 are located at
15   two different points in the circumferential direction. The
number of the strain gauges need not be two, but may be three
or more.

The tolerance ring 19 need not be provided in an
20   auxiliary device driven by the belt 18. The tolerance ring 19
may be provided in a power source, which is the engine E
driving the belt 18. In this case, the tension T1 of a
section of the belt 18 at the trailing side of the crankshaft
pulley 17 and the tension T3 of a section of the belt 18 at
25   the advancing side of the crankshaft pulley 17 are obtained,
and then, based on the obtained tensions T1 and T3, the load
torque M0 of all the auxiliary devices is obtained. For
example, the tolerance ring 19 is provided between the housing
of the engine E that, with a bearing, rotatably supports the
30   crankshaft of the engine E, and the outer race of the bearing.

The deformation member need not be annular like the
tolerance ring 19, but may be a C-shaped member that is formed
by removing a part of the tolerance ring 19. The deformation
35   member may comprise discontinuous members that support the

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bearing 20 relative to the boss 13 as long as the discontinuous members support the bearing 20 arranged at intervals less than 180° in the circumferential direction.

5   The endless loop power transferring member does not need to be a belt, and rotors with which such a member is engaged do not need to be pulleys. For example, the endless loop power transferring member maybe a chain, and the rotors may be sprockets.

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The present invention does not necessarily applied to a drive source (the engine F) of a vehicle and auxiliary devices. However, the present invention may be applied to endless loop power transferring members other than ones used

15   in vehicles. Specifically, the present invention may be applied to a case where torque is transmitted from a power source such as an electric motor to rotary machines through an endless loop power transferring member.

20   The present examples and embodiments are to be considered as illustrative and not restrictive and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.